U.S. Army Research Institute
for the Behavioral and Social Sciences

Research Report 1681

A Comparison of Two Alternative Velocity Vector Cue Combinations for the AH-64D Integrated Helmet and Display Sight Subsystem

John E. Stewart, II
U.S. Army Research Institute

June 1995

U.S. ARMY RESEARCH INSTITUTE
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13. ABSTRACT (*Maximum 200 words*)
The AH-64A employs an integrated helmet and display sight subsystem which presents night vision system and flight data to the pilot's right eye. Velocity vector and acceleration cues tell the pilot when the aircraft is accelerating, its speed, and vector. A 6 kt cue is used for hovering; a 60 kt cue for transition. A single 20 kt cue was proposed for the AH-64D. The requirement was dropped, but the question remained as to whether the 20 kt cue provided any advantage. The experiment was conducted to answer this question. Ten AH-64A pilots performed a mission consisting of seven Aircrew Training Manual (ATM) tasks, under 1-day and 2-night conditions (6/60 kt and 20/60 kt cues) in the simulator training research advanced testbed for aviation (STRATA). The STRATA copilot-gunner station was used with a rear-projection display. Of 210 task events, 209 met ATM standards. Performance across all tasks was better in the 6/60 than in the 20/60 condition ($p < .04$, two-tailed). Performance on stationary hover reached significance ($p < .05$) and approached significance for three other hovering tasks. Results supported retention of the 6 and 60 kt cues.

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A Comparison of Two Alternative Velocity Vector Cue Combinations for the AH-64D Integrated Helmet and Display Sight Subsystem

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FOREWORD

The research described in this report was conducted by the Simulation Team of the U.S. Army Research Institute Rotary-Wing Aviation Research Unit (ARI) at Fort Rucker, Alabama. ARI is committed to enhancing aviation training. A cornerstone of this commitment is the simulator training research advanced testbed for aviation (STRATA). STRATA is a dedicated simulation research platform of modular design which can be reconfigured to represent simulators and training devices of varying complexity. In this way, STRATA can be used to test the training impact of various training device configurations, including alternative displays and symbologies.

The present research effort was initiated subsequent to a request from the TRADOC Systems Manager (TSM) for the AH-64D Apache Longbow helicopter. The AH-64 employs an integrated helmet and display sight subsystem (IHADSS) which presents dynamic flight symbology to the pilot's right eye. Two important symbols are the velocity vector and acceleration cues. Theses tell the pilot when the aircraft is beginning to accelerate, the current speed in knots (kt), and predicted direction of movement. The AH-64A has a 6 kt velocity vector cue, used for precision hover and hover modes of flight, and a 60 kt cue that is engaged during transition from lower to higher speed modes. These cues were to be replaced with a single 20 kt cue for the AH-64D IHADSS. Many experienced AH-64A pilots believed that this would be detrimental to pilot performance, especially in the lower speed modes, where the 6 kt cue provides important feedback on airspeed and drift. TSM-Longbow believed that the requirement for a 20 kt cue across all three modes would degrade performance, but had anecdotal, rather than empirical, evidence to support this belief. Further, the TSM was reluctant to prejudge the 20 kt cue without such evidence; indeed, it could conceivably confer performance advantages in some flight modes.

For the experiment, the front cockpit of STRATA was used, with AH-64 pilots performing a scenario consisting of seven tasks in 1-day and 2-night conditions. For the night conditions, the 6/60 or 20/60 kt cues were employed. The results of the research provided empirical support for a decision to retain the current combination of IHADSS velocity vector cues. These findings also suggested research issues regarding selective fidelity and the impact of field of view restriction on performance.

The results of this project were briefed to the TSM-Longbow office in September 1994. A briefing was provided to the Product Manager for Apache-Longbow in January 1995.

EDGAR M. JOHNSON
Director

ACKNOWLEDGMENTS

The concerted, dedicated efforts of key individuals made this project a success. First, Mike Couch and Dale Weiler, both retired Army aviators whose knowledge of rotary-wing simulation is second to none, were instrumental in assisting with the development of the mission scenario, the performance measures, and evaluating the performance of the participants. Rande Hanson spent many long hours formatting and analyzing the performance data. Nick Donker, Rolf Beutler, Fred Zalzal, and other members of the CAE, Inc. simulation team provided vital support in managing and operating the STRATA.

A COMPARISON OF TWO ALTERNATIVE VELOCITY VECTOR CUE COMBINATIONS FOR THE AH-64D INTEGRATED HELMET AND DISPLAY SIGHT SUBSYSTEM

EXECUTIVE SUMMARY

Requirement:

The integrated helmet and display sight subsystem (IHADSS) for the AH-64A Apache helicopter displays 6 and 60 knot (kt) velocity vector cues to assist the pilot in managing airspeed, acceleration, heading, and drift during precision hover (bob-up), hover, and transitional modes of flight. The AH-64D Longbow variant of the aircraft was to incorporate a 20 kt velocity vector cue for all three flight modes. An alternative plan proposed the addition of the 20 kt cue to the hover mode, retaining the 6 kt cue for precision hover and the 60 kt cue for transition. Neither option was supported by empirical data. The TRADOC Systems Manager (TSM) for Apache Longbow requested that ARI perform a controlled experiment to compare the alternative cue combinations.

Procedure:

Ten participants, all AH-64 instructor pilots (IP), performed a flight scenario in the simulator training research advanced testbed for aviation (STRATA) consisting of seven Aircrew Training Manual (ATM) tasks. A three-screen, rear-projection display was used. Each participant performed the scenario under baseline (day), and 2-night (6/60 kt and 20/60 kt) conditions. Participants were told to perform each task to ATM standards. The 2-night conditions were systematically counterbalanced. Two retired Army aviators served as independent raters for each task. Automated performance measures were captured in addition to the real-time ratings.

Findings:

Of a total of 210 task events (10 participants x 7 tasks x 3 conditions), 209 were performed to the level of ATM standards. Both the real-time ratings and automated performance measures indicated that performance was superior under the 6 kt cue condition. Comparing real-time ratings, the differences were significant for the task of stationary hover, and closely approached statistical significance for hover taxiing and hovering out of ground effect. The automated performance measures supported the differences found via the real-time ratings, and sometimes detected subtle performance differences

that the real-time ratings did not show (e.g., greater roll during normal takeoff in the 20 vs. the 6 kt conditions).

Utilization of Findings:

The results of this research have provided guidance to TSM-Apache Longbow and to the Apache Longbow Product Manager. Partially as a result of the present research, TSM-Apache Longbow has decided to retain the current 6 and 60 kt velocity vector cues. The results suggest that the addition of a 20 kt cue would add nothing in terms of useful feedback and could even degrade performance, especially in the various modes of hovering flight. The findings also suggest that the low-cost, rear-projection display of STRATA may be suitable for skills sustainment; future research comparing systematically different display configurations could shed light on the optimal configuration for a low-cost, transportable, skills-sustainment training device.

A COMPARISON OF TWO ALTERNATIVE VELOCITY VECTOR CUE COMBINATIONS FOR THE AH-64D INTEGRATED HELMET AND DISPLAY SIGHT SUBSYSTEM

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Introduction

Background

Night Vision System (NVS) tradeoffs. Developments in NVS technology have redefined the Army helicopter's mission within the past decade. Modern attack helicopters, like the AH-64A Apache, have integral electro-optical systems, such as the pilot night vision system (PNVS) and target acquisition designation system (TADS). Although there is no doubt that NVS systems add unprecedented mission capabilities to military helicopters, unanswered questions remain about their effects on pilot performance (Kaiser & Foyle, 1991). For increased night mission effectiveness, performance tradeoffs can be expected.

One obvious tradeoff is the reduced field of view (FOV) which, for the AH-64A PNVS, is 40° horizontal x 30° vertical. Armstrong, Hofmann, Sanders, Stone, & Bowen (1975) found that the restriction of FOV to 40° resulted in reduced accuracy in ground speed estimates under night vision goggle (NVG) conditions when compared with a 60° NVG FOV. Although the research literature on the adverse effects of NVGs on pilot performance is sparse (Ruffner, Grubb, & Hamilton, 1992), one survey of self-reported perceptual problems (Crowley, 1991) seems consistent with what one would expect, knowing the FOV and visual acuity degradations. The most frequently reported problems from the sample of 221 Army aviators were (a) undetected aircraft drift, (b) illusory drift, (c) faulty height judgment, and (d) disorientation. Since drift and height estimation are critical to helicopter flight under NVS operational conditions, it is puzzling that empirical research on the use of the PNVS is extremely rare.

NVGs are binocular, whereas the AH-64 PNVS system is a monocular helmet-mounted display (HMD) in which forward-looking infrared radiation imagery and aircraft state symbology are presented only to the pilot's right eye. McLean & Smith (1987), in their review of HMD research, concluded that NVS imagery should be binocular, but that there was insufficient data to determine whether the presentation of symbology should be monocular or binocular. Consequently, it is likely that the lack of binocular cues for the AH-64A PNVS could exacerbate those perceptual problems outlined above. Likewise, the physical distance between the pilot's eye and the PNVS, which is located on a turret on the nose of the aircraft and below the pilot's eyepoint, could create situational awareness problems, especially for those maneuvers which require scanning and the use of peripheral vision and/or cockpit reference cues (e.g., lateral motion cues; canopy frame elevation relative to horizon).

Integrated helmet and display sight subsystem (IHADSS) symbology. Monocular PNVS imagery and flight symbology are presented to the AH-64A pilot's right eye via the IHADSS. Key parts of the symbology are the 6 and 60 knot (kt) velocity vector cues. The movement and acceleration cues provided by the vector symbology are intended to aid the pilot in controlling drift and keeping velocity constant during bob-up (precision hover), hover, and transitional modes of flight (e.g., approach and landing) during NVS operations. The modes are selected via a switch on the pilot's cyclic control stick. In its present configuration, the velocity vector cues for the IHADSS are: bob-up 6 kt; hover, 6 kt; transition, 60 kt. Cues are not present for the cruise mode. The 6 and 60 kt velocities are somewhat arbitrary.

Figure 1 provides a simplified graphic illustration of the dynamics of velocity vector and acceleration cuing for the hover mode (0 to 6 kt). The perspective is a "top down" view of the aircraft. The first picture (top left) shows the appearance of the velocity vector and acceleration cues during a stationary hover. Since there is no forward movement or momentum, the acceleration cue appears centered in the line of sight (LOS) reticle, with the tip of the velocity vector cue superimposed on it. The second illustration shows the aircraft beginning to move diagonally to the right. The acceleration cue has moved toward the right forward quadrant. A few seconds later, if the aircraft is allowed to continue moving in the same direction, the velocity vector cue would move outward to touch the acceleration cue. This would indicate that the aircraft has stopped accelerating and has reached a constant velocity. As long as there is no acceleration, the cue remains at the tip of the velocity vector.

The bottom row of illustrations shows dynamic changes during a hover taxi. The aircraft is taxiing forward; the pilot provides a slight right cyclic input which causes the acceleration cue to indicate that the aircraft will soon be moving diagonally to the right in relation to its present forward velocity. In the second illustration, the velocity vector moves toward and touches the acceleration cue, indicating the aircraft is now moving in the intended direction, and no longer accelerating. If the aircraft were decelerating, the cue would move back down the vector toward the LOS reticle, and the vector would follow it.

The final illustration shows the appearance of the cues when the velocity vector is saturated (the aircraft is going faster than 6 kt). When this happens, referencing of the acceleration and velocity vector cues changes. Since the velocity vector is now longer than the 6 kt length, the acceleration cue can no longer sit on top of it. It reverts to the center of the LOS reticle if there is no acceleration. If the aircraft accelerates, it moves upward along the vertical axis of the reticle; for deceleration it moves in the opposite direction.

This set of cues tells the pilot to (a) reduce speed, or (b) shift to the transition mode (60 kt cue).

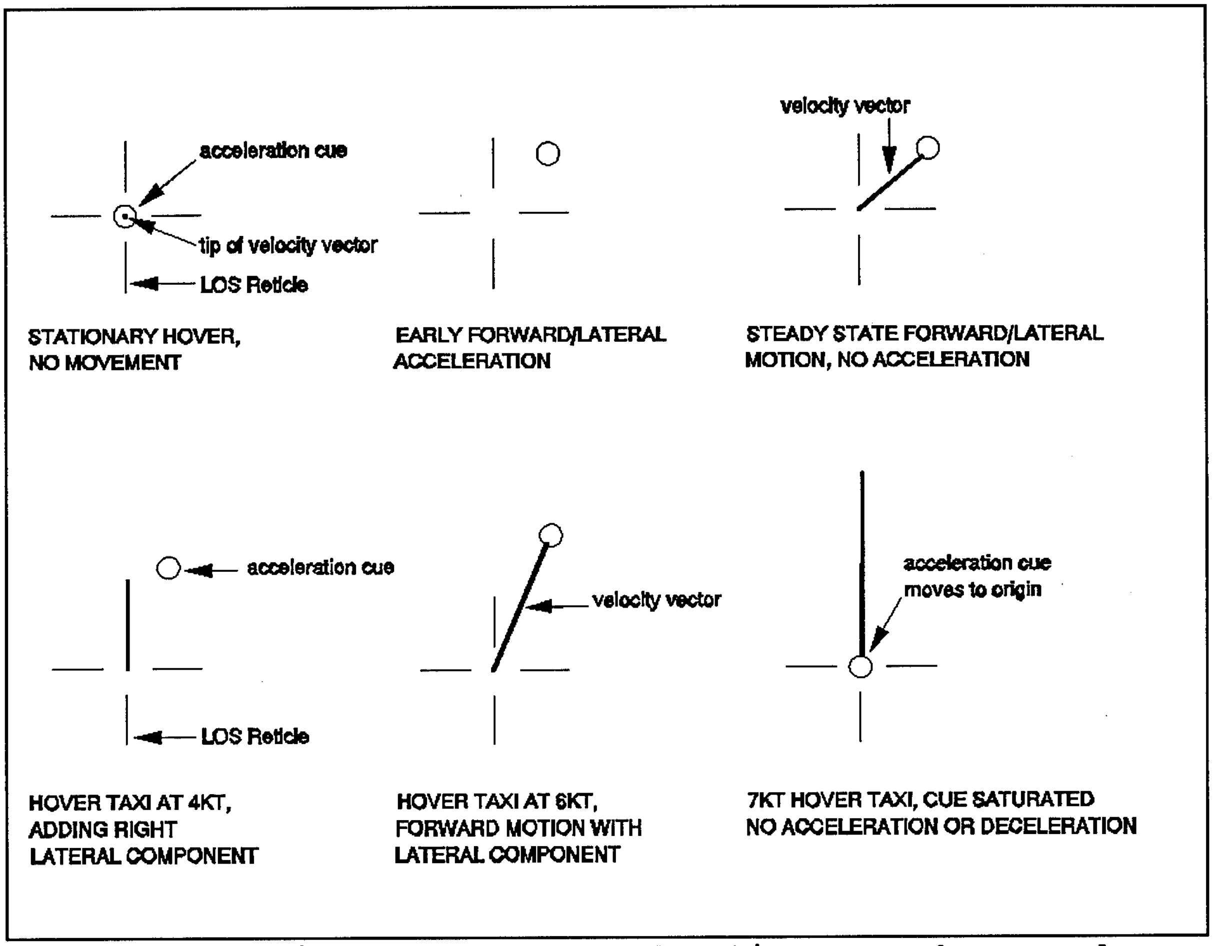

Figure 1. Velocity vector and acceleration cues, hover mode.

<u>The 20 kt velocity vector</u>. The proposed symbology for the AH-64D Apache Longbow, a later variant of the aircraft equipped with an advanced automated radar and an enhanced CRT-display cockpit, was to consist of a single 20 kt velocity vector, across all three flight modes. Experienced AH-64 test pilots believed this vector to be inadequate for some flight regimes, especially during night operations. While hovering at night, the acceleration and vector cues could appear too late to make drift corrections, resulting in less stability and greater drift; in short, the cues may tell the pilot where he has been, not where he is going. Consequently, the original requirement for the across-the-board 20 kt velocity vector was dropped.

<u>Utility of the 20 kt velocity vector</u>. There may be situations where the 20 kt vector, in addition to the other two, would be helpful. Hover taxiing and termination of a normal

approach to a hover are potential flight modes where the 20 kt velocity vector may provide useful information. In the absence of controlled experimentation, there are no empirical data to demonstrate that the 20 kt vector adds anything to the two currently available. An experimental comparison of the 20-60 and 6-60 kt velocity vector combinations would provide objective evidence as to which cue is best and under what circumstances.

Overview of Velocity Vector Simulation

STRATA. The simulator training research advanced testbed for aviation (STRATA) is a reconfigurable simulator designed for investigating the training effectiveness of different combinations of vision, motion, control loading, aeromodels, and other simulator subsystems. In its present configuration, it represents the AH-64A helicopter. A detailed description of STRATA and its various components can be found in Kurts & Gainer (1991). STRATA was configured to simulate the 6 and 20 kt velocity vector cues. This was done by presenting the 20 kt cue in the hover mode on half the experimental trials. In this way, an experiment was designed which systematically compared the 20 and 6 kt hover vectors in the context of aircrew training manual (ATM) aviator tasks. A scenario consisting of ATM tasks was constructed for this purpose.

Backward transfer and mission scenario. The backward transfer paradigm (Adams & McAbee, 1961) is a means of demonstrating how well flight simulators approximate the performances of aircraft (Kaempf, Cross, & Blackwell, 1989; Stewart, 1985). A recent backward transfer experiment (Stewart, 1994) found STRATA to be a valid representation of the AH-64A when pilots flew a simulated scenario consisting of maneuvers based on 13 ATM tasks.

The scenario selected for the present experiment included ATM tasks from the Stewart (1994) experiment. These were stationary hover, hovering in-ground effect, hover taxi, hovering turns, normal takeoff (NTO), and confined area landing (CAL). Normal visual meteorological conditions (VMC) approach and landing to a hover and hover out-of-ground effect (HOGE) were not included in the original experiment, but were added to the present one, because they were considered pertinent to the 20 kt velocity vector.

The simulation began at Falcon Field, Mesa, Arizona. First, the pilot was instructed by air traffic control (ATC) to perform a stationary hover, maintaining a commanded heading; next, he hover taxied to the departure end of the active runway, where he performed a left hovering turn, followed by a HOGE. Next, he performed an NTO, then flew on a preassigned heading to a forward arming and refueling point (FARP) located at the foot of Red Mountain, approximately 13 km northeast from Falcon Field. There he performed a CAL. After making a takeoff from the FARP, he was instructed by ATC to fly a preassigned heading, returning to

Falcon Field, where he performed a normal VMC approach and landing to a hover. The estimated performance time for this scenario was 45 minutes.

Hypotheses

Some hypotheses would seem reasonable in light of lessons learned. Based upon anecdotal evidence from experienced pilots who have flown both the A and D variants of the AH-64, it would be reasonable to assume that performance on hover tasks, as well as performance across all tasks, would be superior with the 6 kt vs 20 kt vector. Thus, for all those tasks performed primarily in the hover mode, the 6 kt cue should be superior to the 20 kt cue. It is conceivable that for tasks requiring the transition from higher to intermediate to lower speeds (e.g., normal approach to a hover), the 20 kt velocity vector may prove advantageous. However, we must also consider the fact that AH-64 pilots have no experience with velocity cues other than 6-60 kt, and the unfamiliarity of the 20 kt cue may mask any of its potential advantages. Consequently, it is reasonable to expect negligible differences for those tasks in which low-speed and hovering flight play little or no role.

Method

Participant Background Characteristics

Ten rated AH-64A aviators with pilot in command (PC) orders, current and proficient in NVS flying, from an operational training unit, were invited to participate. None were current in STRATA, although one had flown the simulator 18 months previously. They used the copilot/gunner station, or forward cockpit of STRATA, which has an IHADSS display identical to that used in operational AH-64As. The forward cockpit, in its current configuration, is equipped with a three-channel (left-right-center) rear projection screen display. Field of view (FOV) is 174° horizontal x 45° vertical, with a resolution of 3.5 arcminutes. The center screen presents 2000 polygons vs 1200 for the other two screens. For simulating night operations, the screen was dark and the pilot able to see the visual scene only through the IHADSS display projected to the right eye.

Background data (i.e., total flight hours, date of last flight, types of aircraft flown) on participants were captured via a questionnaire adapted from Stewart (1994; Appendix A). The participants completed the background material before the experiment, and rated the simulation on a (6-point) Likert scale afterward. All participants were males, with a mean age of 33.90 years (SD = 4.18). The oldest was 40, the youngest 26 (rounded to the nearest year). Table 1 presents experience data on the sample of ten participants, based upon self-reports on the questionnaire. NVS hours and NVS currency data were missing for one participant. The grand means for each question item were substituted for the missing data.

Table 1

Participant Background Data

Variable	Mean	SD	Minimum	Maximum
Pilot in command (PC) hours	762.00	485.68	200.00	1500.00
Pilot (PI) hours	178.00	199.10	0.00	600.00
Days since last flight	3.10	4.33	1.00	15.00
Months since last checkride	4.60	2.76	1.00	8.00
Combat Mission Simulator (CMS) hours	237.00	95.92	90.00	400.00
Days since last CMS light	56.80	73.61	1.00	240.00
Night Vision System (NVS) hours	296.70	153.70	80.00	570.00
Days since last NVS flight	14.80	11.79	1.00	30.00

Experimental Design

Because of the limited pool of eligible participants, the most efficient design was a within-subjects design, or two-factor (condition and tasks) repeated measures experiment. Each participant performed seven ATM tasks under each of two PNVS vector cue combination conditions, and one day baseline condition. This resulted in a total of 21 iterations per participant. Table 2 presents the experimental design.

Table 2

Experimental Design

Vector (N=10)	ATM Tasks (Night)						
6/60	Hover (6)	Hover Taxi (6)	Hovering Turn (6)	Hover OGE (6)	Normal Takeoff (6-60)	Confined Area Landing (60-6)	VMC Approach to a Hover (60-6)
20/60	Hover (20)	Hover Taxi (20)	Hovering Turn (20)	Hover OGE (20)	Normal Takeoff (20-60)	Confined Area Landing (60-20)	VMC Approach to a Hover (60-20)
	ATM Tasks Baseline Comparison (Day)						
6/60	Hover	Hover Taxi	Hovering Turn	Hover OGE	Normal Takeoff	Confined Area Landing	VMC Approach to a Hover

Procedure

Upon reporting to the experiment, the participant was given a premission briefing in which the purpose of the experiment and the mission scenario were described. Each participant was familiarized with those components of the front cockpit unique to STRATA (the pneumatic motion cuing seat or G-seat, and the visual display). He was told that if at any time he experienced symptoms of simulator sickness or nausea, to report these, and the experiment would be halted, at his option. Pilots flew a predetermined night mission profile held constant for all participants. The mission scenario was designed to incorporate events where (1) the pilot is dependent on the IHADSS for motion cues; (2) both low and high-velocity vectors must be used; and (3) where low-speed and/or hovering flight comprised at least a part of each task. Before flying a night mission, pilots flew the mission scenario in a baseline (day) condition. This was done in order to collect performance data for backward (aircraft-to-simulator) transfer, using the alternative rear-projection display of STRATA, and to familiarize the participant with the simulator. This was followed by the (6-60/20-60) night mission scenario. The order in which the two night scenarios were presented was systematically counterbalanced. Pilots were instructed to perform the tasks in the scenario to ATM standards, and to follow standard procedures for using the IHADSS. This required using the hover mode during the performance of all tasks, and shifting between hover and transition modes for four of the seven tasks. The bob-up mode was not used because it

would provide participants in the 20 kt hover condition with a 6 kt velocity vector, which could be used as an "illegitimate" aid to hovering and low-speed flight.

Independent variables. Recall that three basic within-subjects conditions were employed: 6-60 or 20-60 kt hover/transition vector cues, and a day or baseline condition. Originally it was planned not to use the IHADSS in the baseline condition. However, a malfunction of the front cockpit optical relay tube visual display unit necessitated use of the IHADSS in HMD mode during baseline for the last eight participants, since this was the only way the front-seat pilot would have radar altimeter data. In HMD mode, the pilot sees a daytime view with the symbology superimposed on the combiner lens of the IHADSS. The eyepoint is the same as for an out-the-window view.

Dependent variables. Two independent judges provided real-time ratings of participant performance. Automated performance measures from the backward transfer experiment were also employed. Successful performance was defined by ATM standards for each task. Two retired Army helicopter pilots (PI); one, a former AH-64 instructor pilot (IP) with over 1,000 PC hours in the aircraft; the other, a retired Army aviator with over 1,000 PC hours in the OH-58, provided concurrent real-time performance ratings for each task. A Likert-type rating form was adapted from that employed by Stewart (1994). The rating form appears in Appendix B.

Results

Reports of Simulator Sickness

One participant reported symptoms of simulator sickness. This was not due to the nature of the simulation itself, but to the fact that the simulation had to be "frozen" abruptly in order to trouble-shoot a technical problem with the terrain database. When the problem was solved, the simulation was "unfrozen." These abrupt changes apparently induced symptoms of nausea, so the participant was excused from the experiment. There were no other reports of simulator sickness prior or subsequent to this incident. This participant was replaced with an alternate.

Performance Based on Real-Time Ratings

Inter-rater reliability. PI real-time ratings of performance used a 5-point scale ranging from 1 (unsatisfactory) to 5 (very good). A rating of 3 represented average performance. All ratings were referenced to the formal ATM performance criteria for the task. The paired ratings of the two independent judges were correlated, across all 210 task events (10 participants; 21 events each). The resultant Pearson r of .72 (df = 208; p <.001) indicated acceptable levels of inter-judge reliability. The paired ratings were compared via a t-test for

paired means. The t-ratio ($t = 1.16$, $df = 209$, $p < .24$, two-tailed) indicated no significant differences due to judges. Ratings from the two judges were averaged.

Order effects. A t-test for paired means revealed no significant order effects for the two night cue conditions (all t-ratios < 1.00). Participant performance was unaffected by which night scenario was performed first.

Total performance scores. The ratings for each participant were summed across all tasks to yield a total score. The grand mean of these scores, across all tasks and cue conditions, was 25.48 ($SD = 4.84$). The scores for all participants ranged from 14 to 33; the maximum possible was 35 (5 points X 7 tasks). Of the 210 total task events, 209 (99.52%) were performed to a level satisfying ATM standards.

Baseline (daytime) performance. The mean total performance score for this condition was 28.65 ($SD = 2.63$). Participants had no problems performing the ATM tasks in the baseline conditions. None of the 70 task events was rated as indicating unsatisfactory performance. There were four instances (5.71%) of below average performance (marginal to unsatisfactory), for stationary hover, hover taxi, hovering turns, and VMC approach to a hover.

Performance based on cue conditions. Total performance scores were: ($M = 25.45$; $SD = 4.02$) for the 6-60 kt cue condition and ($M = 22.35$; $SD = 5.50$) for the 20-60 kt cue condition. The performance of the participants on the seven ATM tasks showed the same order of cue conditions across all tasks (1. Baseline; 2. 6-60; 3. 20-60). Comparison of total mean performance scores via a paired means t-test showed that participants performed significantly better under the 6-60 than under the 20-60 velocity vector cue conditions ($t= -2.36$, $df = 9$, $p < .04$).

In the 6-60 kt cue condition, there were eight instances (11.43%) of performance rated below average (two for hovering turns; one each for HOGE, NTO and CAL, and three for VMC approach to a hover). By contrast, 18 instances (25.71%) of below average performance occurred in the 20-60 kt cue condition (four in hover, two in hover taxi, one in hovering turns, one in HOGE, three in NTO, two in CAL, and five in VMC approach to a hover). These data were converted to an (X+1) transformation because of the large number of zeros. A t-test for paired means, comparing the 6-60 and 20-60 cue conditions, was significant in the direction of the latter cue condition ($t = -2.24$, $df = 9$, $p < .05$). The only unsatisfactory rating occurred in the 20-60 kt cue condition, for the hovering turn.

For no single ATM task was it evident that the 20 kt velocity vector cue afforded any performance advantage. Performance as a function of task and cue condition is presented graphically in Figure 2. Results of t-tests appear Table 3.

The t-tests are between the 6-60 and 20-60 cue conditions. An examination of Table 3 shows that of the seven comparisons, one (hover) attained conventional two-tailed significance levels. A negative t-ratio signifies that the difference is in the direction favoring the 6-60 kt condition.

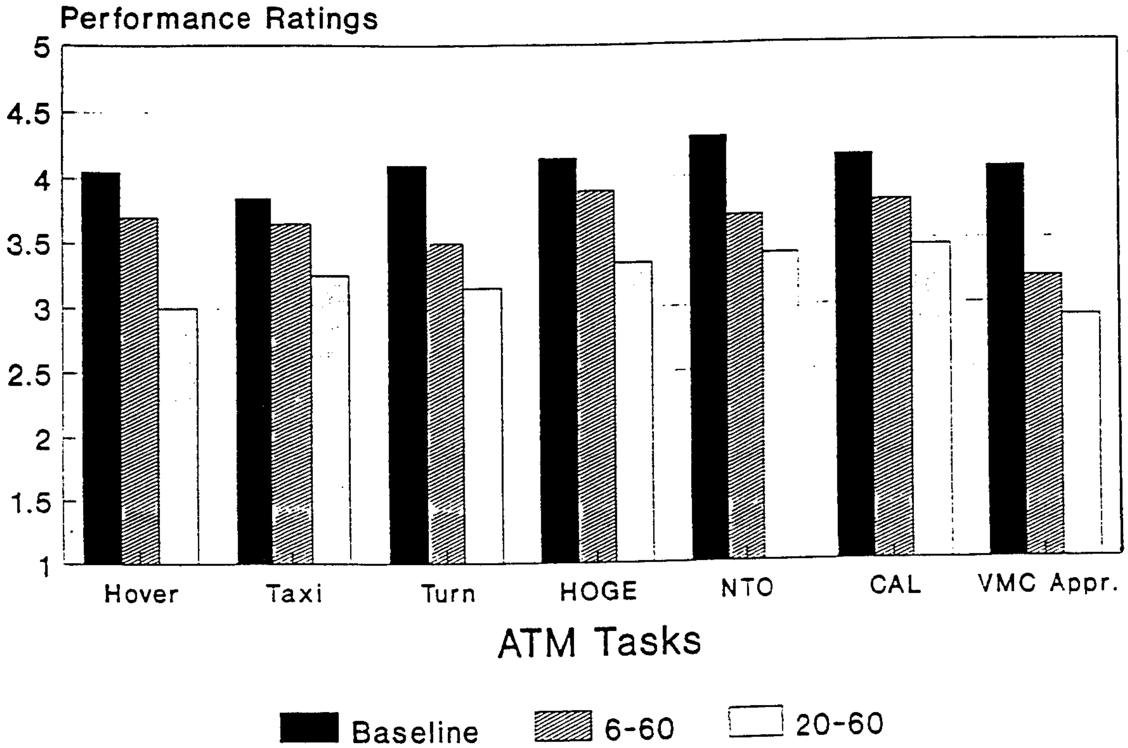

Figure 2. Performance as a function of task and cue condition.

Table 3

Comparisons between Mean Performance Ratings on 6-60 and 20-60 Cue Conditions for Seven ATM Tasks

ATM Task	Hover	Hover Taxi	Hover Turn	HOGE	NTO	CAL	VMC
t- ratio	-2.26	-2.18	-1.56	-2.01	-1.33	-1.29	-1.03
p (2-tail)	.05	.06	.15	.08	.21	.24	.32

Performance Based on Background Data

Background data and performance. The self-report data from the questionnaire (see Table 1) were correlated with total performance scores for each participant. Because some of the self-report data showed variation greater than the mean, the

scores were converted into ranks, and a Spearman rank order correlation coefficient was computed for each of the variables shown below in Table 4.

Table 4

Spearman Rank-Order Correlation of Background Questionnaire Data with Total Performance Scores

Variable	1	2	3	4	5	6	7	8	9	10
1. PC hr.										
2. PI hr.	-.51									
3. Last Flt.	.09	-.17								
4. Checkride	-.52	-.19	.13							
5. CMS hr.	.39	.29	.34	-.72*						
6. Last CMS	-.44	.32	.09	.43	-.06					
7. NVS hr.	.85*	-.35	.03	-.66*	.56	-.35				
8. Last NVS	-.31	.15	-.20	-.15	-.02	-.06	.11			
9. Baseline	.73*	.03	.03	-.82*	.78*	-.52	.71*	-.23		
10. 6-60	.14	.46	-.60	-.67*	.43	-.07	.22	-.04	.57	
11. 20-60	.33	.04	-.61	-.35	.00	-.35	.05	-.41	.43	.58

* Critical value (2-tail, .05)= .65

PC hours correlated highly with performance in the baseline (day) condition ($p < .025$). The correlation between elapsed time since last flight and performance in the two vector cue conditions approached significance via a two-tailed test ($p < .06$). The elapsed time since the last checkride was negatively correlated with performance in the baseline condition ($p < .005$), as well as with the 6-60 cue condition ($p < .05$). One very interesting correlation was between total number of hours in the combat mission simulator (CMS) and performance in the baseline condition ($r_s = .78$, $p < .01$). The more CMS hours reported, the better the performance in STRATA. The CMS is an AH-64 simulator with a full motion base and a CRT visual display system, making it quite different from the STRATA configuration used in this experiment.

Correlations with individual task performance. The same background data were also correlated with rated performance on the seven tasks comprising each scenario. The following summary will cite those correlations that attained or closely approached conventional .05 (two-tailed) probabilities. All correlations were logically consistent with expectations.

For the baseline scenario, the first task, stationary hover, was significantly correlated with PC hours ($r_s = .76$), and months since last checkride ($r_s = -.63$); correlation with NVS hours

approached significance ($\underline{r}_s$ =.57, $\underline{p}$ <.08). Hover taxi correlated with days since last CMS session ($\underline{r}_s$ = -.71), and normal takeoff with months since last checkride ($\underline{r}_s$ = -.68). Confined area landing was correlated with PC hours ($\underline{r}_s$ = .79) and days since last NVS flight ($\underline{r}_s$ = -.64). The latter correlation was interesting because this was a daytime scenario; a possible explanation is the fact that radar altimeter data are only available in the front cockpit through the VDU or the IHADSS displays. Likewise, currency in the use of the IHADSS may reinforce effective scan patterns. Finally, VMC approach to a hover was significantly correlated with hours in the CMS ($\underline{r}_s$ = .77).

For the 6-60 kt scenario, hover taxi performance was correlated with PI hours ($\underline{r}_s$ = .72). Confined area landing and VMC approach were correlated with months since last checkride ($\underline{r}_s$ = -.80; -.82, respectively); the more time elapsed since the last checkride, the worse the participant's performance. The correlation between NVS hours and performance on the VMC approach and landing closely approached significance ($\underline{r}_s$ = .58, $\underline{p}$ <.08).

For the 20-60 kt scenario, the time (days) since last flight correlated significantly with performance on the hover taxi ($\underline{r}_s$ = -.64), and closely approached significance for hover OGE ($\underline{r}_s$ = -.58, $\underline{p}$ <.08).

<u>Background data and ratings of STRATA fidelity</u>. Table 5 presents the post-experimental ratings of STRATA from the questionnaire. Participants were asked to indicate the degree of similarity/dissimilarity between STRATA and the AH-64 on 11 dimensions. The rating scale ranged from 1 (very different) to 6 (very similar). A rating of 4 indicates moderate perceived similarity. The first item is a general, or global, rating of the degree of similarity between STRATA and the aircraft.

Table 5

Similarity Ratings of STRATA to the AH-64

Dimension	Mean	SD	Min.	Max.
General	4.20	1.03	2.00	6.00
Pitch	3.60	1.35	1.00	5.00
Roll	3.90	1.10	2.00	5.00
Yaw	4.50	1.08	2.00	6.00
Acceleration	3.90	1.37	2.00	6.00
Cyclic	3.10	1.20	1.00	5.00
Collective	4.30	0.95	2.00	5.00
Hover	3.90	1.52	1.00	6.00
Pedals	4.50	1.18	2.00	6.00
Turns	4.30	1.25	2.00	6.00
Power	3.90	1.66	1.00	6.00

An examination of Table 5 reveals that participants rated STRATA's handling characteristics as moderately similar to those of the aircraft. Pitch control was perceived as least similar; movement about the yaw axis as most similar. Grand mean was 4.01, indicating moderate similarity overall. Participants in a Stewart (1994) experiment were asked to make the same ratings. The grand mean of the latter experiment was 4.79, which indicated that those participants perceived STRATA's handling characteristics to be more similar to the AH-64's than did the present group. The vision systems were quite different; the original experiment used the stereoscopic fiber optic helmet mounted display whereas the present experiment used the three-screen rear-projection system. The participants in the present experiment were instructors from an operational training unit, who tended to have considerably more flight hours than their counterparts in the original STRATA backward transfer experiment.

Either of these factors alone (or an interaction of both) could have accounted for these differences.

Performance Based on Data Recording and Analysis (DRA) Measures

Overview. The following DRA performance measures, recorded at the rate of 1 Hz, were used in the present analyses: collective (pitch control) displacement (in), drift (m), heading (degrees), lateral and longitudinal cyclic (pitch control) displacement (in), pitch and roll (degrees), altitude above ground level (AGL; ft), airspeed (kt), and rate of climb (fpm). Drift data were collected only for stationary hovering tasks, while rate of climb data were collected only for those tasks that involved takeoff, approach, and landing.

A detailed analysis of all of the DRA measures for all of the ATM tasks is beyond the scope of the present research. Nonetheless, an examination of the reliability of DRA measures for those tasks that are most germane to the issue of the optimal velocity vector cue combinations would seem warranted. DRA output was compared across cue conditions for stationary hover, hover taxi, hovering turns, and HOGE. A fifth ATM task not involving hovering (NTO) was also analyzed in the same fashion, comparing performance measures between cue conditions.

Stationary hover. Comparisons were made between several automated measures for the hover task, which was the first in the seven-task scenario. Modes of hovering flight were selected as testbeds for DRA performance measurement principally because the ATM criteria are more explicit and permit less variation than for non-hover tasks (e.g., CAL, NTO). Selected measures were (mean) drift, heading, pitch, roll, altitude AGL, and airspeed. For the 6-60 and 20-60 scenarios, only drift and heading showed significant differences. DRA data were missing, due to a technical problem, on the 20-60 kt scenario for the first participant. The grand mean of the performance measures was substituted for the 20-60 kt scenario measures for this participant.

A t-test for paired means was performed on each of these performance measures. For drift, the respective means and standard deviations were: (6-60); 1.63 m, .71; and (20-60) 2.76 m, .62. A t-ratio of -3.29 was significant in the expected direction ($df = 9$; $p < .01$) indicating that participants drifted significantly less when using the 6 kt than when using the 20 kt cue. It would seem reasonable to expect the more NVS hours and the fewer days since the last NVS flight, the less would be the drift while hovering. These variables were correlated with mean drift for each participant. NVS hours showed no significant correlation with drift in either of the two velocity vector conditions. However, time since last NVS flight did correlate significantly, and in the direction expected, for drift in the 20 kt cue condition ($r_s = .75$, $p < .025$), indicating that the more recent the last NVS flight, the less the drift. This finding

also implies that those participants who were more NVS-current were able to adapt to the 20 kt cue, or were less dependent on it. No other comparisons were significant.

A total of at least 30 repeated measures was taken on each subject within each task. Range and variability data were obtained for each of the performance measures. Consistent with the rationale for the hypotheses, it would be reasonable to expect the range to be greater for the 20 kt than for the 6 kt cue condition.

Range (highest-lowest) data for drift, roll, altitude, and airspeed were compared between velocity vector cue conditions via paired means $\underline{t}$-tests. The range of drift was less in the 6 kt ($\underline{M}$ = 2.92 m) than in the 20 kt ($\underline{M}$ = 5.54 m) condition. The respective ranges for airspeed were: $\underline{M}$ = 1.00 (6 kt) and $\underline{M}$ = 1.60 (20 kt). The $\underline{t}$-ratios for drift ($\underline{t}$ = -3.03; $\underline{p}$ <.01) and airspeed ($\underline{t}$= -2.71; $\underline{p}$ < .02) were significant. For the stationary hover, no other differences in range were significant.

The standard deviations for all participants were compared for each of the performance measures. The $\underline{t}$-ratios for drift ($\underline{t}$ = -3.27, $\underline{p}$ < .01) and heading ($\underline{t}$ = 2.61, $\underline{p}$ < .03) attained two-tailed significance levels. Again, it appears that though less drift occurred in the 6 kt condition, there was more variation in heading (or more movement on the yaw axis). However, it seems that differences in heading variation were quite small for the present group of highly proficient participants ($\underline{SD}$ = 1.90, 6 kt; 1.47, 20 kt). Furthermore, the range of heading change (yaw) was not significantly different when the 6 and 20 kt cue conditions were compared ($\underline{Ms}$ = 5.02°; 4.15°, respectively). Thus, more movement about the yaw axis in the 6 kt cue condition may have had little practical significance in terms of performance.

<u>Other hovering-related tasks</u>. Paired-means $\underline{t}$-tests were also run for three other tasks (hover taxi, hovering turns, and HOGE). There were no significant differences for any of these measures when means were compared. However, a few of those differences which approached significance, are nevertheless important in the context of safety. During hover taxi, there was a tendency for participants in the 20 kt cue condition to taxi faster than those in the 6 kt cue condition ($\underline{t}$ = -1.96, $\underline{p}$ < .08). Also, the airspeed standard deviation for the 20 kt condition was greater ($\underline{t}$ = -2.15, $\underline{p}$ < .06), indicating more speed variability when the 20 kt cue was used. When ranges of airspeed for the 6 and 20 kt cue conditions were compared ($\underline{Ms}$ = 2.30 kt; 4.80 kt, respectively), the difference was significant ($\underline{t}$ = -2.34, $\underline{p}$ < .04), showing better speed control in the 6 kt cue condition. These differences were consistent with what we would expect, given the different lengths of the vectors. When taxiing at the ATM-prescribed pace of a brisk walk (approximately 4 kt), the 6 kt cue is quite evident, whereas the 20 kt cue is less obvious. Thus saturation of the cue (analogous to "pegging" a speedometer) in the 6 kt condition is an indication that the specified speed

has been exceeded; in the 20 kt condition, this helpful cue did not exist.

NTO. ATM task 5 was a NTO from the ground. The DRA data for this task were analyzed in order to determine their utility for evaluating performance on a specimen task that did not involve hovering, but required acceleration from low to moderate speeds during its inception. The performance criteria for NTO are less explicit than for the stationary hover. Different ATM criteria pertain to different segments (initiation/climbout) phases of the task. For example, the pilot should maintain his heading + or - 10° throughout the task, and maintain the desired rate of climb + or - 100 fpm, and desired airspeed + or - 10 kt. Obviously, only the first of these variables would apply during the first phase of the task, since the pilot has not yet reached his target airspeed and constant climb rate. (For these participants, the average heading range was well within the constraints ($M = 6.42^{\circ}$, 6 kt cue; $M = 7.91^{\circ}$, 20 kt cue). There are also different ways in which the task can be successfully accomplished: for example, the pilot can make an "altitude over airspeed" takeoff, trading off airspeed for altitude, or an "airspeed over altitude" takeoff, where airspeed is built up before climbing out. The 6 or 20 kt cues would be employed during the initial phase of the task, in which the aircraft lifts off the ground and begins to accelerate to effective translational lift (ETL) which is approximately 15-20 kt. For this reason, comparison between the two cue conditions was made during the first ten seconds of the task (the first segment).

There are some NTO performance criteria which connote good and poor control. For example, an examination of the real-time ratings revealed that both raters frequently cited excessive roll control and pitch control in both PNVS conditions. During the first segment it is critical that the pilot stabilize the aircraft, minimizing roll and heading (yaw) variation. Thus lateral movement of the cyclic pitch control should be minimal. Application of power should be smooth and consistent, with a minimum of power changes (minimal variation of the collective pitch control). Consequently, for Segment 1, standard deviation and range data were examined for collective, roll, yaw, and lateral cyclic (each segment comprised ten repeated measures). It was anticipated that at the initial segment of the NTO, the lack of the 6 kt cue would make the maintenance of roll and yaw control more difficult than when the cue was present.

Comparisons partially supported this expectation. Although a paired means t-test on SD and range data revealed no differences due to the collective pitch control or yaw when comparing the 6 and 20 kt conditions, the differences in standard deviations for roll ($t = -2.52$, $p < .04$) and lateral cyclic ($t = -2.45$, $p < .04$), were significant, with more roll in the 20 kt cue condition.

The same results were obtained for roll and lateral cyclic displacement, using the range of movement during the 10 sec period (respective $\underline{t}$s = -2.95, $\underline{p} < .01$; -2.36, $\underline{p} < .04$). Therefore it appeared that, in initiating the NTO, roll stability was more of a problem with the 20 kt velocity vector cue than for the 6 kt cue. The increased tendency to roll when operating under NVS conditions was easily noted during real-time observation of participant performance in STRATA. This may be due in part to the fact that during NVS operations, field of view is substantially reduced. Add to this the absence of the 6 kt vector and acceleration cue that could signal the early onset of a roll, and the control problem becomes more pronounced. Mean roll ranges, across all participants, were 8.9° for the 6 kt cue condition; 12.35° for the 20 kt condition. Although not specifically pertinent to performance on this task, it is interesting to note that when in the 6 kt cue condition participants initiated the NTO at a lower mean airspeed ($\underline{M}$ = 7.86 knots) than in the 20 kt condition ($\underline{M}$ = 10.38 knots). The difference was significant ($\underline{t}$ = -2.95, $\underline{p} < .01$).

Real-time performance ratings for NTO correlated significantly with the range measures for roll in the 6 kt ($\underline{r}_s$= -.71, $\underline{p} < .025$) and 20 kt ($\underline{r}_s = -.66$, $\underline{p} < .05$) cue conditions. The same real-time ratings did not correlate significantly with lateral cyclic range data in the 6 kt cue condition ($r_s = -.19$), but did in the 20 kt cue condition ($\underline{r}_s = -.84$, $\underline{p} < .01$). This finding implies that pilots had more difficulty compensating for the increased movement about the roll axis in the 20 kt cue condition, hence the greater lateral cyclic range ($\underline{M}$ = .72 in) in the 20 kt than in the 6 kt condition ($\underline{M}$ = .50 in). Rated performance correlated significantly with range of collective movement in the 20 kt ($\underline{r}_s = -.83$, $p < .01$), but not in the 6 kt ($\underline{r}_s = -.38$) condition. In the former condition, the more movement of the collective (the more power changes) the lower the performance rating. Comparative <u>SD</u> data for NTO are presented below in Table 6; range data appear in Table 7. Spearman intercorrelations of real-time ratings and roll data appear in Table 8.

Table 6

DRA Standard Deviation Data for Normal Takeoff, Segment 1

Performance Measures	Collective		Roll		Yaw		Cyclic	
	Cue conditions (kt)							
Participants and Ratings (6 vs 20 kt)	6	20	6	20	6	20	6	20
1. 4.5/4.0	.24	.24	2.48	3.51	1.94	2.51	.21	.20
2. 2.0/2.5	.05	.25	3.25	5.75	.83	5.71	.13	.38
3. 3.5/2.0	.29	.39	3.72	5.19	3.66	3.44	.13	.37
4. 4.0/3.0	.21	.32	2.52	3.72	2.38	3.43	.16	.24
5. 3.0/2.5	.13	.26	4.89	6.37	1.42	2.31	.17	.29
6. 4.0/4.0	.20	.30	2.99	2.05	2.80	2.92	.19	.17
7. 4.5/4.0	.22	.19	2.89	2.09	2.52	2.2	.18	.13
8. 4.0/3.5	.24	.36	1.89	3.08	.86	1.72	.11	.21
9. 3.0/4.0	.39	.02	3.85	3.89	3.05	1.76	.18	.19
10. 4.5/4.5	.30	.24	2.62	3.54	3.42	1.19	.12	.20

Table 7

DRA Range Data for Normal Takeoff, Segment 1

Performance Measures	Collective		Roll		Yaw		Cyclic	
	Cue conditions (kt)							
Participants and Ratings (6 vs 20 kt)	6	20	6	20	6	20	6	20
1. 4.5/4.0	.67	.72	9.2	10.60	5.00	7.20	.63	.61
2. 2.0/2.5	.18	.85	10.5	18.90	2.40	17.30	.50	1.22
3. 3.5/2.0	.87	1.05	11.90	18.20	9.90	10.50	.47	1.07
4. 4.0/3.0	.64	.90	8.40	10.80	6.20	9.40	.49	.75
5. 3.0/2.5	.40	.96	13.20	19.50	4.40	6.30	.57	.86
6. 4.0/4.0	.64	.76	8.30	7.30	8.90	8.70	.49	.50
7. 4.5/4.0	.70	.62	4.80	5.90	6.90	6.70	.50	.39
8. 4.0/3.5	.56	.94	6.00	10.20	2.50	.80	.33	.78
9. 3.0/4.0	1.26	.07	10.80	11.40	8.40	4.70	.55	.49
10. 4.5/4.5	.78	.72	5.90	10.70	9.70	3.60	.46	.51

Table 8

Spearman Intercorrelations for DRA Roll Data

Variables	1.	2.	3.	4.	5.
1. Rating, 06 kt	1.00				
2. Rating, 20 kt	.68	1.00			
3. Roll sd, 06 kt	-.71	n.s.	1.00		
4. Roll sd, 20 kt	-.75	-.66	.64	1.00	
5. Roll rng, 06 kt	-.77	-.67	.70	.82	1.00
6. Roll rng, 20 kt	-.79	-.66	.65	.98	.85

$\underline{p}$ critical (.05, 2-tail) = .63; n.s. = nonsignificant.

All of the correlations in Table 8 except one are significant, and in the expected direction. The finding that real-time ratings in the 6 kt condition predicted roll range and standard deviation in the 20 kt condition almost as well as in the 6 kt condition is intriguing. This probably indicates both consistency in participant performance and also reliability of the ratings. The high positive correlations between roll DRA measures between these two conditions lends further evidence of consistency. Participants with the good roll control in one condition also manifested good control in the other condition.

It seems, then, that the DRA measures for NTO performance showed sensitivity to the velocity vector cue conditions, in the direction expected. The DRA measures, in that they showed significant differences, appeared more sensitive to performance differences than did the real-time ratings, although both were correlated in a manner consistent with expectations.

Discussion

Velocity Vector Cues

The results of the present experiment show clear advantage for the 6 kt velocity vector cue, for any of the ATM tasks performed. For most tasks the performance differences (based on real-time ratings) between the two cue conditions approached but did not attain conventional levels of statistical significance. For those tasks that relied primarily upon hovering flight, (e.g., stationary hover, hover taxi, and HOGE) the differences were either significant or closely approaching the conventional .05 (two-tailed) level. This is consistent with the expectations of subject matter experts familiar with the AH-64A's IHADSS symbology. For none of the seven ATM tasks was performance with the 20 kt cue better than for the 6 kt cue. The descending order

of performance across all these tasks was: Baseline (Daylight)/6-60/20-60. The single performance measure for which the 20 kt cue was superior (based on DRA data output) involved maintaining a constant heading while hovering; participants seemed to show less heading variation (less range) for the 20 kt as opposed to the 6 kt cue. However, this may have simply been an artifact of pilots compensating for drift.

DRA output appeared to be very useful in diagnosing and interpreting performance differences between the two cue conditions. Recall that real-time rating differences for NTO were nonsignificant. Still, it was evident that the 20 kt velocity vector cue induced significantly greater excursion about the roll axis than did the 6 kt cue, and this performance problem was reflected in greater lateral movement of the cyclic pitch control in an attempt to compensate for it. Real-time ratings also correlated highly with roll excursion during the first ten seconds of NTO, confirming that induced roll was an important performance criterion.

In conclusion, it appears that the current IHADSS velocity vector cues are satisfactory, and that the addition of a new cue would not be justified. Both real-time subjective and automated objective performance measures indicated the possibility of performance deficits if the 20 kt cue were adopted.

The reason why the performance differences between cue conditions were obtained is somewhat more difficult to explain. First, the 20 kt cue could have been inherently inferior to the 6 kt cue in providing velocity and acceleration data to the pilot. Second, we must keep in mind that all of the pilots in the present sample were NVS-proficient, and had not flown with any other cue combination besides 6-60. Thus, the performance decrement could be due to a negative transfer of training brought about by the introduction of an unfamiliar cue. Therefore, some of the inherent advantages of the 20 kt cue, if there were any, could have been masked by this negative transfer effect. Nonetheless, it would seem that the possibility of a negative transfer and the consequent need to re-adapt to new symbology would further militate against any major change in velocity vector symbology. If there is a need to re-adapt, then this would be reflected in increased training time and costs, and the more experienced the pilot with NVS flight, the greater the need for retraining.

Suggestions for Future Research

FOV has been shown to be of critical importance for those piloting tasks dependent on the use of peripheral cues (Westra, Sheppard, Jones, & Hettinger, 1987; Woodruff, Longridge, Irish, & Jeffreys, 1979). Still, it remains unclear just what the FOV requirements should be for modular, low-cost rotary-wing simulators. In the present experiment, FOV was restricted under NVS conditions. The real-time ratings indicated that performance

was degraded to some degree for all ATM tasks performed in the scenario. The degradation was greatest for hovering turns, NTO, and VMC approach. These are tasks where pilots must rely heavily upon peripheral and vertical motion cues, and where the displacement of the eyepoint could detract from situational awareness. These findings seem consistent with research which has shown that restricted FOV can degrade performance under these conditions.

The potential training impact of FOV restriction remains moot, especially in the case of helicopter operations using NVS devices. A systematic program of research using a balanced experimental design and an eye-tracking device could reveal such important information as (1) differences in scan patterns and cue utilization in restricted vs full-FOV conditions; (2) the effects of NVS proficiency on compensation for the loss of peripheral and cockpit reference cues; (3) instructional strategies for optimizing NVS flight performance; and (4) training device FOV requirements for those aviator tasks which are heavily dependent on peripheral cues.

References

Adams, J. A., & McAbee, W. H. (1961). A program for a functional evaluation of the GAM-83 Melpar Trainer (Rep. No. APGC-TN-61-41). Eglin AFB, FL: U.S. Air Force Air Proving Grounds. (AD 268220)

Armstrong,. R. N., Hofmann, M. A., Sanders, M. G., Stone, L. W., & Bowen, C. A. (1975). Perceived velocity and altitude judgments during rotary-wind aircraft flight (USAARL Rep. 76-3). Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory.

Crowley, J. S. (1991). Human factors of night vision devices: Anecdotes from the field concerning visual illusions and other effects (USAARL Rep. 91-15). Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory.

Kaempf, G. L., Cross, K. D., & Blackwell, N. J. (1989). Backward transfer and skill acquisition in the AH-1 flight and weapons simulator (ARI Research Rep. 1537). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences. (AD A213 432)

Kaiser, M. K., & Foyle, D. C. (1991). Human factors issues in the use of night vision devices. Proceedings of the Human Factors Society 35th Annual Meeting (pp. 1502-1506). Santa Monica, CA: Human Factors Society.

Kurts, D., & Gainer, C. A. (1991). The use of a dedicated testbed to evaluate simulator training effectiveness. Piloted Simulation Effectiveness Conference, AGARD Conference Proceedings No. 513 (pp. 11-1 to 11-9). Brussels, Belgium: North Atlantic Treaty Organization.

McLean, B., & Smith, S. (1987). Developing a wide field of view HMD for simulators. Proceedings of the Society of Photo-optical Instrumentation Engineers (pp. 79-82). Bellingham, WA: Society of Photo-optical Engineers.

Ruffner, J. W., Grubb, M. G., & Hamilton D. B. (1992). Selective factors affecting rotary wing aviator performance with symbology superimposed on night vision goggles (ARI Research Rep. 1622). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences. (AD A254 983)

Stewart, J. E. (1985). Learning and performance in an air refueling part-task trainer: a preliminary data analysis. Proceedings of the Human Factors Society 29th Annual Meeting (pp. 408-411). Santa Monica, CA: Human Factors Society.

Stewart, J. E. (1994). Using the backward transfer paradigm to validate the simulator training research advanced testbed for aviation (ARI Research Rep. 1666). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences. (AD A285 758)

Westra, D. P., Sheppard, D. J., Jones, S. A., & Hettinger, L J. (1987). Simulator design features for helicopter shipboard landings II: Performance experiments (NTSC Tech. Rep. 87-041). Orlando, FL: Naval Training Systems Center.

Woodruff, R. R., Longridge, T. M., Irish, P. A., & Jeffreys, R. T. (1979). Pilot performance in simulated aerial refueling as a function of tanker model complexity and visual display field-of-view (HRL Tech. Rep. 78-79). Williams AFB, AZ: U.S. Air Force Human Resources Laboratory.

APPENDIX A

Participant Questionnaire
Velocity Vector Experiment

PARTICIPANT QUESTIONNAIRE: Velocity Vector Experiment

Participant Number__________

Call Sign_______________

We are interested in the effectiveness of the velocity vector cues that are part of the IHADSS symbology. The AH-64A, as you know, has two vector and acceleration cues (6/60 KT). A single 20 KT velocity vector cue has been proposed for the AH-64D. At present, there is little empirical data as to which cues are optimal and under which conditions. For this reason we are performing an experiment to determine the relative effectiveness of velocity vector cues for different routine modes of flight.

For this experiment, you will be asked to "fly" a simulator representing the AH-64. The simulator is called STRATA (Simulator Training Research Advanced Testbed for Aviation). You will be flying the aircraft from the copilot/gunner's station, which has a rear-projection screen display. The terrain database represents the Phoenix-Mesa, Arizona, metropolitan area.

PART I: BACKGROUND QUESTIONNAIRE

There are a few questions that we would like to ask, for data analysis only, before we begin. This is ANONYMOUS, and there is no way that your name and other identifying characteristics can be determined. We have simply assigned you a number corresponding to the order in which you performed the experiment. This is for STATISTICAL PURPOSES ONLY.

1. How many PC/IP hours have you had in the AH-64 ? ________ hours.

2. How many PI hours have you had in the AH-64?_____hours.

3. What is the APPROXIMATE date of your last flight in the AH-64? __________.

4. How long has it been since your last CHECKRIDE in the AH-64? ________months.

5. Indicate below the approximate hours you have had in other aircraft, including fixed-wing.

Aircraft	APPROXIMATE Hours	APPROXIMATE Date of Last Flight

6. What is your age, rounded to the nearest year?_____

7. What is your current rank?______

8. Approximately how may hours have you had in the AH-64 Combat Mission Simulator (CMS)? __________hours. About how long has it been since your last CMS session?____________.

9. Have you flown STRATA before? _______Yes ________No
IF YES, Approximately when?____________.

10. Please estimate your total AH-64 NVS hours_________.
Approximate date of last NVS flight_________.

PART II: EVALUATION OF SIMULATION EXERCISE

PLEASE COMPLETE THIS SECTION AFTER YOU HAVE PERFORMED THE SIMULATED FLIGHT SCENARIO. We are interested in the degree to which STRATA models the performance of the actual aircraft. Your responses to the following questions would be of great value to us. Please indicate your impressions by placing and **X** in the appropriate box below:

1. IN GENERAL, how SIMILAR were the flight characteristics of STRATA to those of the AH-64?

Very Different	Different	Somewhat Different	Somewhat Similar	Similar	Very Similar

IN PARTICULAR: How would you judge the SIMILARITY of the following performance characteristics of STRATA to those of the AH-64 ?

2. Control about the PITCH axis.

Very Different	Different	Somewhat Different	Somewhat Similar	Similar	Very Similar

3. Control about the ROLL axis.

Very Different	Different	Somewhat Different	Somewhat Similar	Similar	Very Similar

4. Control about the YAW axis.

Very Different	Different	Somewhat Different	Somewhat Similar	Similar	Very Similar

5. ACCELERATION and DECELERATION.

Very Different	Different	Somewhat Different	Somewhat Similar	Similar	Very Similar

6. Responsiveness to CYCLIC Inputs.

Very Different	Different	Somewhat Different	Somewhat Similar	Similar	Very Similar

7. Responsiveness to COLLECTIVE Inputs.

Very Different	Different	Somewhat Different	Somewhat Similar	Similar	Very Similar

8. Performance during HOVERING.

Very Different	Different	Somewhat Different	Somewhat Similar	Similar	Very Similar

9. Responsiveness to PEDAL INPUTS.

Very Different	Different	Somewhat Different	Somewhat Similar	Similar	Very Similar

10. Performance during TURNS.

Very Different	Different	Somewhat Different	Somewhat Similar	Similar	Very Similar

11. Performance during POWER CHANGES.

Very Different	Different	Somewhat Different	Somewhat Similar	Similar	Very Similar

12. We would be interested in any additional impressions that you may have of the simulation in which you have just participated. We are especially interested in the ways that you found STRATA to be LIKE and UNLIKE the AH-64. If you wish, you can write your impressions below. If you need more space, you can continue on the blank sheet provided.

APPENDIX B

Backward Transfer Performance Ratings
Velocity Vector Experiment

BACKWARD TRANSFER PERFORMANCE RATINGS

Subject Number________________

Call Sign___________________ Rater________________

Please evaluate the performance of the pilot for each of the tasks listed below. Place an X in the box on the rating scale that best represents your judgment of pilot performance. All tasks should be evaluated to ATM standards. If subject received UNSAT on first attempt, allow one repetition. If more than one attempt was necessary, please note below in COMMENTS section.

A. DAYTIME BASELINE CONDITION

FALCON FIELD

1. Takeoff to / maintain stationary hover (HDG 320). (measure for 30 seconds when pilot is ready)

UNSAT	MARGINAL	AVERAGE	GOOD	VERY GOOD

COMMENTS:____
____
____
____

Standards:
maintain altitude 5 ft, +- 2 ft
maintain heading +- 10 degrees
drift not to exceed 3 ft

2. Hover taxi. (measure for 30 seconds when pilot is ready)

UNSAT	MARGINAL	AVERAGE	GOOD	VERY GOOD

COMMENTS:____
____
____
____

Standards:
maintain altitude 5 ft, +- 2 ft
maintain constant hover speed
maintain ground track
drift not to exceed 3 ft

3. Left Pedal Turn. (measure at least 180 degrees of turn when pilot is ready)

UNSAT	MARGINAL	AVERAGE	GOOD	VERY GOOD

COMMENTS:____
____
____
____

Standards:
maintain altitude 5 ft, +- 2 ft
drift not to exceed 3 ft
maintain constant rate of turn

BACKWARD TRANSFER PERFORMANCE RATINGS

4. Hover OGE. (measure for 30 seconds when pilot is ready)

UNSAT	MARGINAL	AVERAGE	GOOD	VERY GOOD

COMMENTS:______________________________

Standards:
maintain heading +- 10 degrees
maintain altitude 100 ft, +- 10 ft
maintain position over runway
drift not to exceed runway edges

5. Normal takeoff. (measure entire maneuver)

UNSAT	MARGINAL	AVERAGE	GOOD	VERY GOOD

COMMENTS:______________________________

Standards:
1. initiate from ground
2. maintain takeoff hdg +- 10 degree
3. maintain gnd trk alignment with takeoff direction w/ min drift
4. a/c in trim above 50 ft AGL
5. accel to desired A/S +- 10 knots
6. maintain rate of climb +- 100FPM
7. maintain takeoff power until min SE A/S

6. Confined area approach and landing. (measure from initiation to termination)

UNSAT	MARGINAL	AVERAGE	GOOD	VERY GOOD

COMMENTS:______________________________

Standards: (excerpts)
1. recon landing area
2. maintain ground track
3. maintain approach angle
4. maintain appropriate rate of closure
5. perform low reconnaissance
6. execute smooth, controlled termination

7. VMC Approach to a hover. (measure when pilot is established on approach until termination)

UNSAT	MARGINAL	AVERAGE	GOOD	VERY GOOD

COMMENTS: ______________________________

Standards:
1. select suitable landing area
2. entry altitude +- 100 ft
3. entry airspeed +- 10 knots
4. maintain gnd track a lignment
5. closure rate NTE brisk walk
6. smooth, controlled termination

BACKWARD TRANSFER PERFORMANCE RATINGS

B. 6/60 VELOCITY VECTOR CUE CONDITION
FALCON FIELD

1. Takeoff to / maintain stationary hover (HDG 320). (measure for 30 seconds when pilot is ready)

UNSAT	MARGINAL	AVERAGE	GOOD	VERY GOOD

COMMENTS:____

Standards:
maintain altitude 5 ft, +- 2 ft
maintain heading +- 10 degrees
drift not to exceed 3 ft

2. Hover taxi. (measure for 30 seconds when pilot is ready)

UNSAT	MARGINAL	AVERAGE	GOOD	VERY GOOD

COMMENTS:____

Standards:
maintain altitude 5 ft, +- 2 ft
maintain constant hover speed
maintain ground track
drift not to exceed 3 ft

3. Left Pedal Turn. (measure at least 180 degrees of turn when pilot is ready)

UNSAT	MARGINAL	AVERAGE	GOOD	VERY GOOD

COMMENTS:____

Standards:
maintain altitude 5 ft, +- 2 ft
drift not to exceed 3 ft
maintain constant rate of turn

4. Hover OGE. (measure for 30 seconds when pilot is ready)

UNSAT	MARGINAL	AVERAGE	GOOD	VERY GOOD

COMMENTS:____

Standards:
maintain heading +- 10 degrees
maintain altitude 100 ft, +- 10 ft
maintain position over runway
drift not to exceed runway edges

BACKWARD TRANSFER PERFORMANCE RATINGS

5. Normal takeoff. (measure entire maneuver)

UNSAT	MARGINAL	AVERAGE	GOOD	VERY GOOD

COMMENTS:____________________

Standards:
1. initiate from ground
2. maintain takeoff hdg +- 10 degree
3. maintain gnd trk alignment with takeoff direction w/ min drift
4. a/c in trim above 50 ft AGL
5. accel to desired A/S +- 10 knots
6. maintain rate of climb +- 100FPM
7. maintain takeoff power until min SE A/S

6. Confined area approach and landing. (measure from initiation to termination)

UNSAT	MARGINAL	AVERAGE	GOOD	VERY GOOD

COMMENTS:____________________

Standards: (excerpts)
1. recon landing area
2. maintain ground track
3. maintain approach angle
4. maintain appropriate rate of closure
5. perform low reconnaissance
6. execute smooth, controlled termination

7. VMC Approach to a hover. (measure when pilot is established on approach until termination)

UNSAT	MARGINAL	AVERAGE	GOOD	VERY GOOD

COMMENTS: ____________________

Standards:
1. select suitable landing area
2. entry altitude +- 100 ft
3. entry airspeed +- 10 knots
4. maintain gnd track a lignment
5. closure rate NTE brisk walk
6. smooth, controlled termination

C. 20/60 VELOCITY VECTOR CUE CONDITION
FALCON FIELD

1. Takeoff to / maintain stationary hover (HDG 320). (measure for 30 seconds when pilot is ready)

UNSAT	MARGINAL	AVERAGE	GOOD	VERY GOOD

COMMENTS:____

Standards:
maintain altitude 5 ft, +- 2 ft
maintain heading +- 10 degrees
drift not to exceed 3 ft

2. Hover taxi. (measure for 30 seconds when pilot is ready)

UN SAT	MARGINAL	AVERAGE	GOOD	VERY GOOD

COMMENTS:____

Standards:
maintain altitude 5 ft, +- 2 ft
maintain constant hover speed
maintain ground track
drift not to exceed 3 ft

3. Left Pedal Turn. (measure at least 180 degrees of turn when pilot is ready)

UNSAT	MARGINAL	AVERAGE	GOOD	VERY GOOD

COMMENTS:____

Standards:
maintain altitude 5 ft, +- 2 ft
drift not to exceed 3 ft
maintain constant rate of turn

4. Hover OGE. (measure for 30 seconds when pilot is ready)

UNSAT	MARGINAL	AVERAGE	GOOD	VERY GOOD

COMMENTS:____

Standards:
maintain heading +- 10 degrees
maintain altitude 100 ft, +- 10 ft
maintain position over runway
drift not to exceed runway edges

BACKWARD TRANSFER PERFORMANCE RATINGS

5. Normal takeoff. (measure entire maneuver)

UNSAT	MARGINAL	AVERAGE	GOOD	VERY GOOD

COMMENTS:______________________________________

Standards:
1. initiate from ground
2. maintain takeoff hdg +- 10 degree
3. maintain gnd trk alignment with takeoff direction w/ min drift
4. a/c in trim above 50 ft AGL
5. accel to desired A/S +- 10 knots
6. maintain rate of climb +- 100FPM
7. maintain takeoff power until min SE A/S

6. Confined area approach and landing. (measure from initiation to termination)

UNSAT	MARGINAL	AVERAGE	GOOD	VERY GOOD

COMMENTS:______________________________________

Standards: (excerpts)
1. recon landing area
2. maintain ground track
3. maintain approach angle
4. maintain appropriate rate of closure
5. perform low reconnaissance
6. execute smooth, controlled termination

7. VMC Approach to a hover. (measure when pilot is established on approach until termination)

UNSAT	MARGINAL	AVERAGE	GOOD	VERY GOOD

COMMENTS: ______________________

Standards:
1. select suitable landing area
2. entry altitude +- 100 ft
3. entry airspeed +- 10 knots
4. maintain gnd track a lignment
5. closure rate NTE brisk walk
6. smooth, controlled termination